THU-PO3-108-07

Study on Conduction Cooling of Superconducting Magnets for the ILC Main Linac

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N. Kimura (ICRR), and V. Kashikhin (FNAL)

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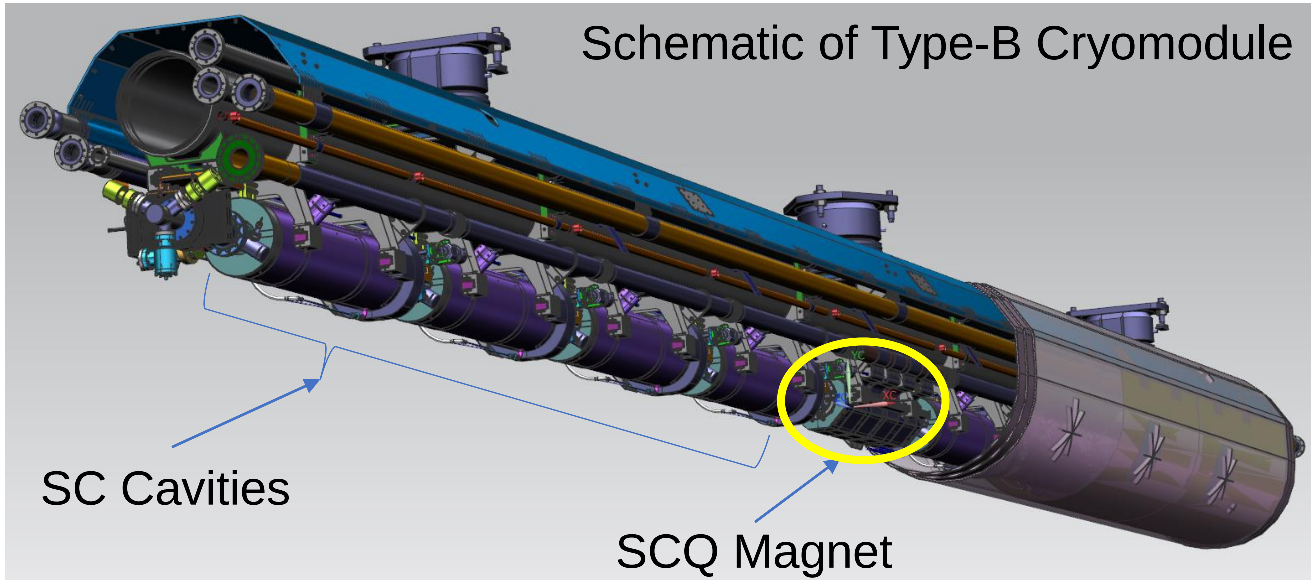
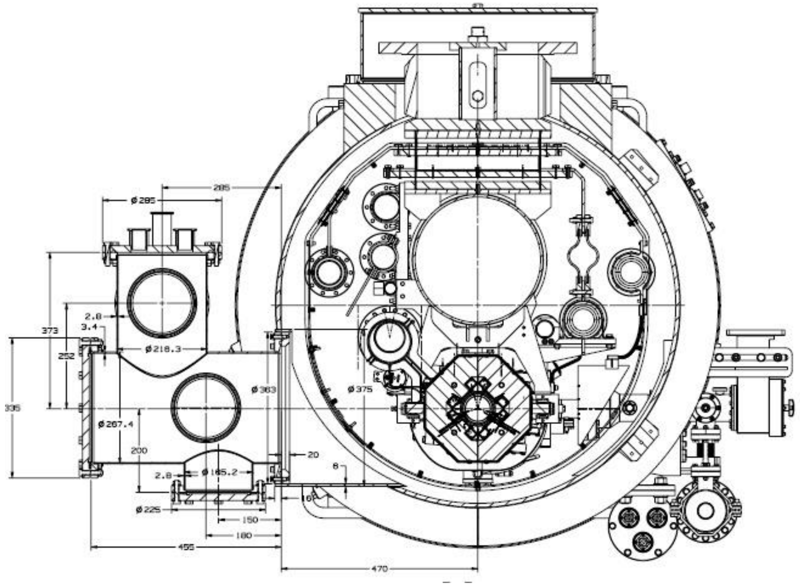
○ Superconducting Quadrupole Magnets for the ILC Main Linac





Courtesy of Y.Orlov (FNAL)

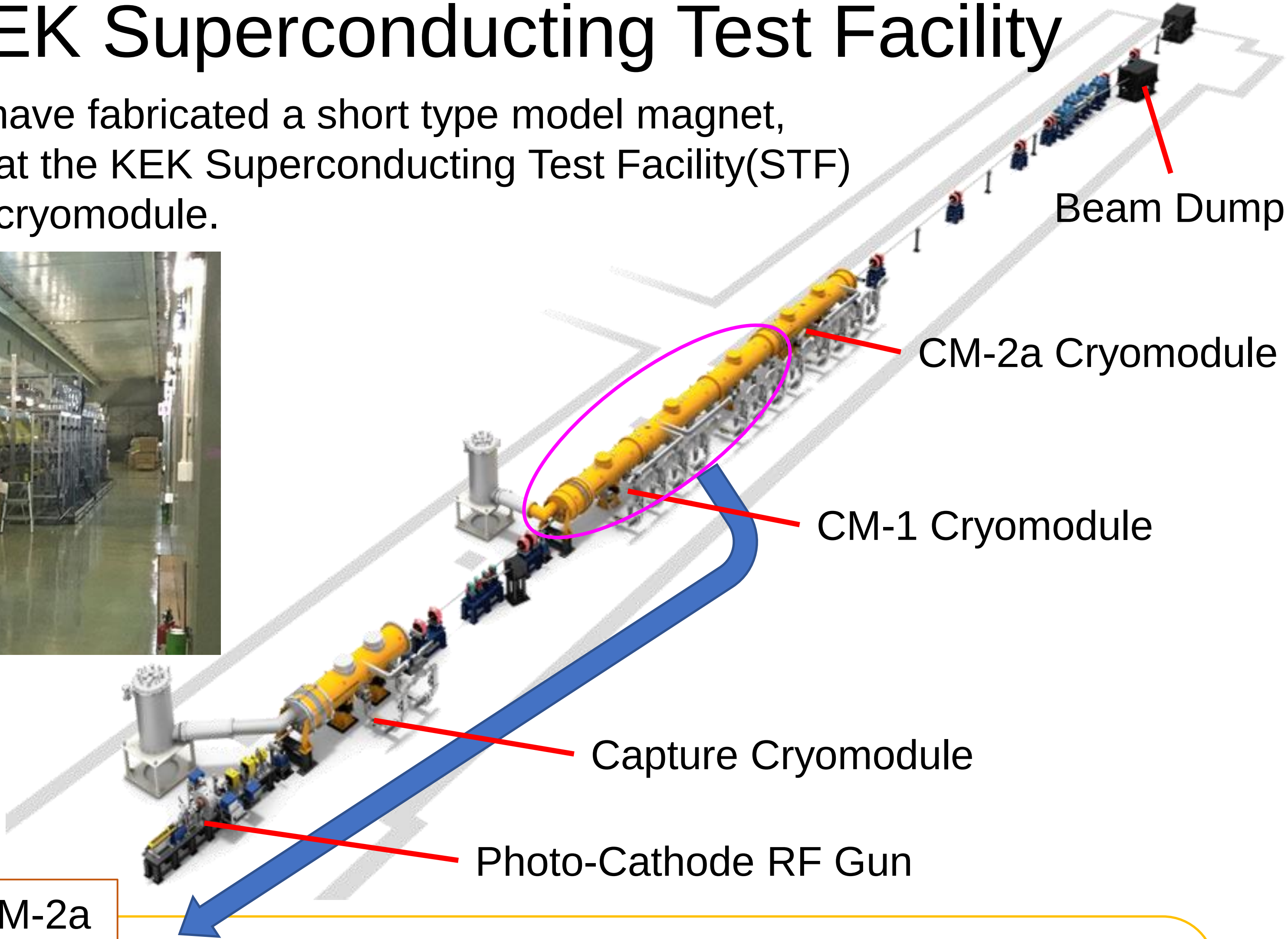
Table 1 : Specification of SCQ Magnet for ILC

Parameters	Low Energy Type	High Energy Type
Beam Energy	5GeV ～ 25 GeV	25 GeV ～ 250 GeV
Physical Length	0.25 m	1 m
Magnetic Length	0.20 m	0.95 m
Radius of Inner Pole	0.045 m	
Field Gradient	19 T/m	40 T/m
Maximum Field of Q-Coil	～ 1.5 T	～ 3 T
Operation Temperature	2 K	

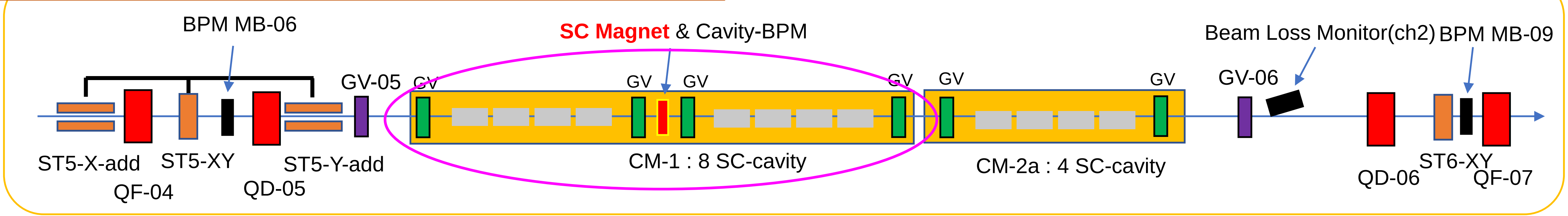
○ Model Magnet R&D in KEK Superconducting Test Facility

- As a magnet R&D program for ILC, we have fabricated a short type model magnet, and installed it into a cryomodule CM-1 at the KEK Superconducting Test Facility(STF) which has the same structure of type-B cryomodule.

Accelerator Tunnel View of KEK-STF



Accelerator Components Including CM-1 and CM-2a

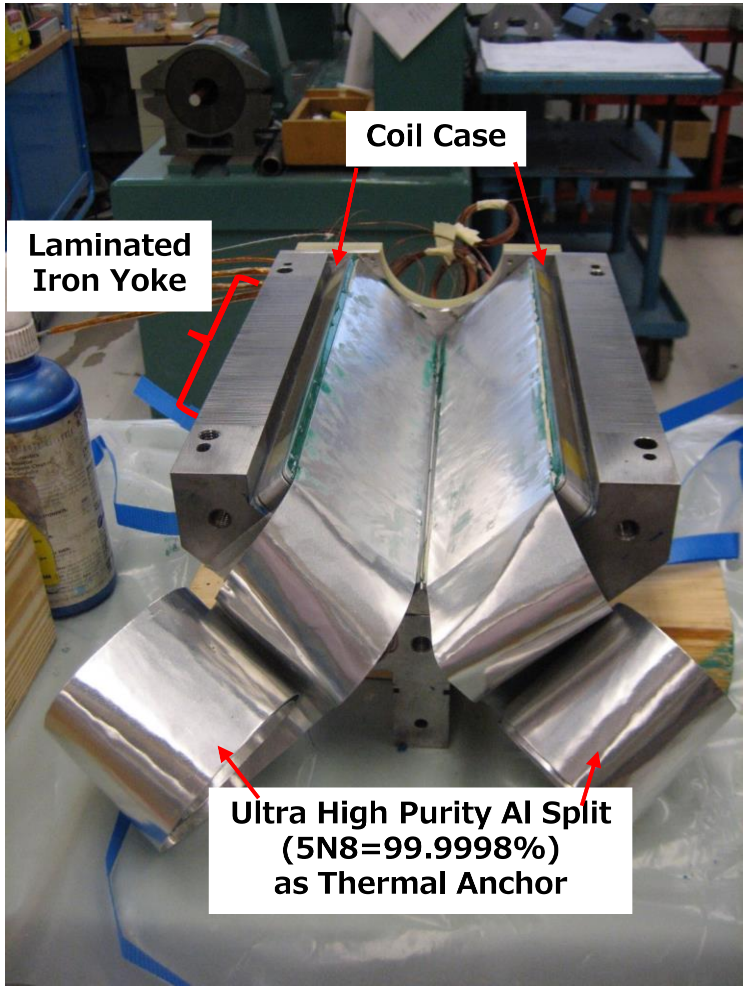


○ Model Magnet R&D in KEK Superconducting Test Facility

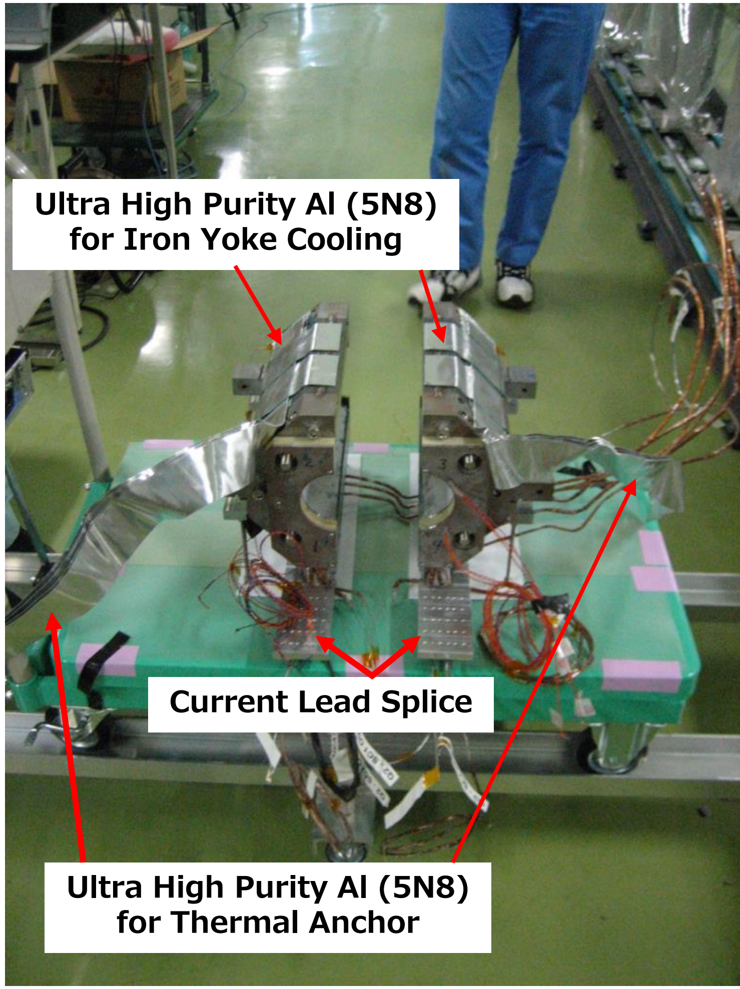
Table2:Installed Model Magnet Package Parameters

Parameter	Unit	Value
Magnet Physical Length	mm	340
Magnet Width	mm	322
Magnet Height	mm	220
Effective Length	mm	230
Magnet Pole Aperture	mm	90
Beam-pipe bore aperture	mm	78
Integrate Peak Gradient	T	2.0
Peak Quadrupole Gradient	T/m	8.7
Quadrupole Magnet Inductance	H	0.66
Operation Current	A	30
Superconductor		NbTi
Superconductor Diameter	mm	0.5

V.Kashikhin *et al*,. "Performance of Conduction Cooled Splitable Superconducting Magnet Package for Linear Accelerators"



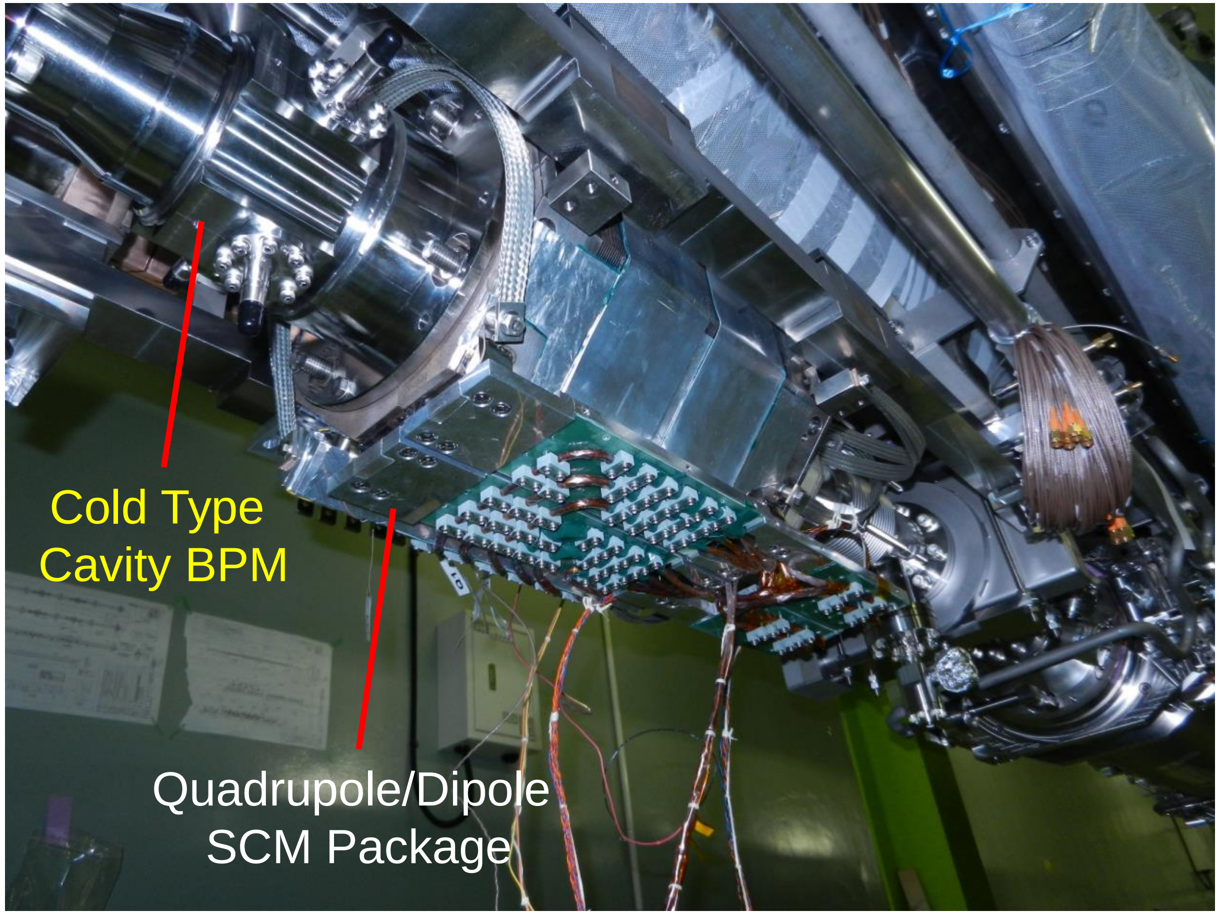
Magnet Fabrication at FNAL

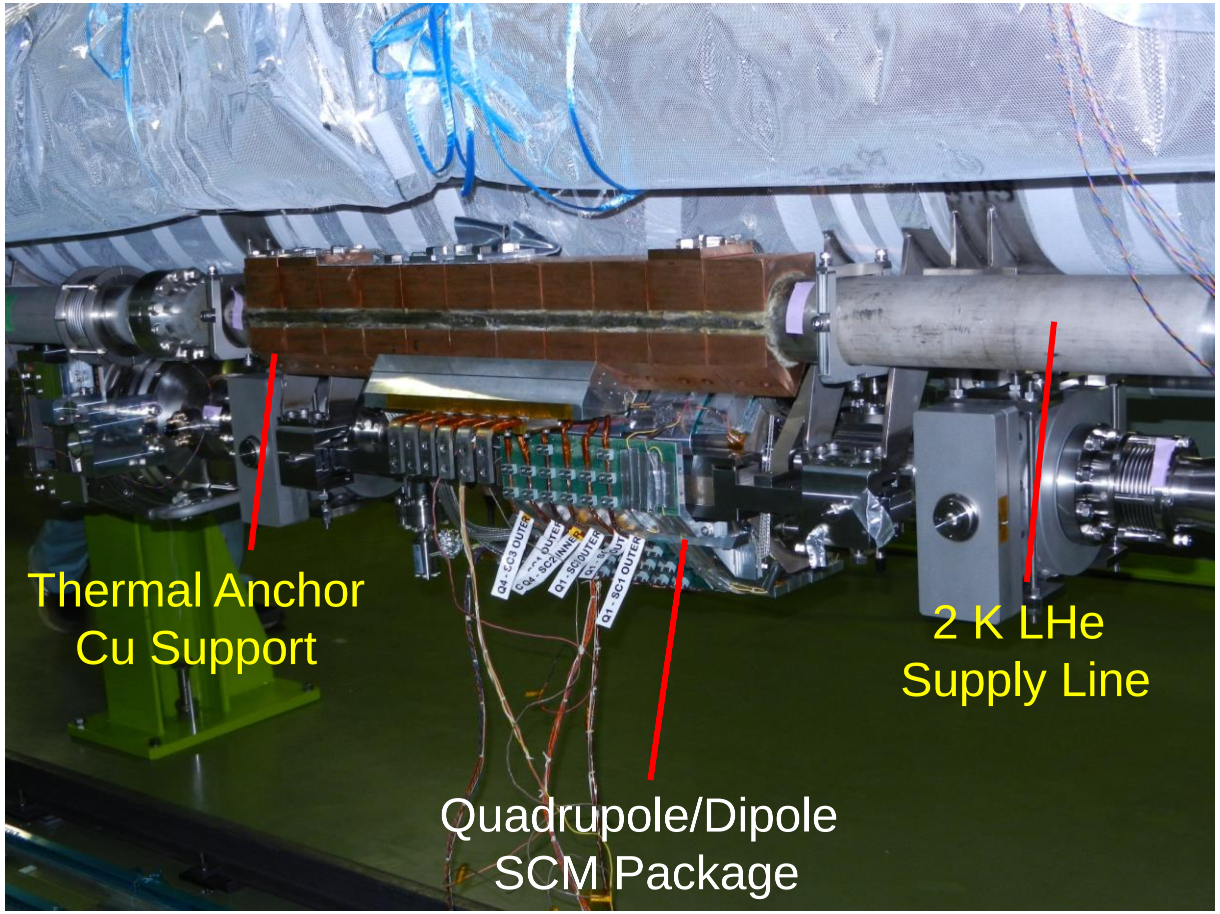


Magnet Installation into STF

○ Model Magnet R&D in KEK Superconducting Test Facility

Model magnet installed into the KEK-STF cryomodule.

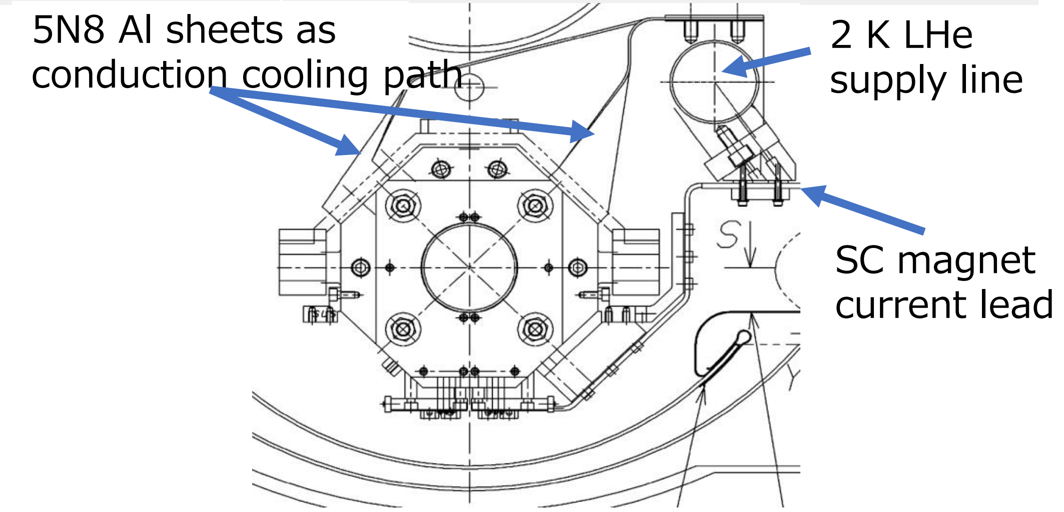




○ Model Magnet R&D in KEK Superconducting Test Facility

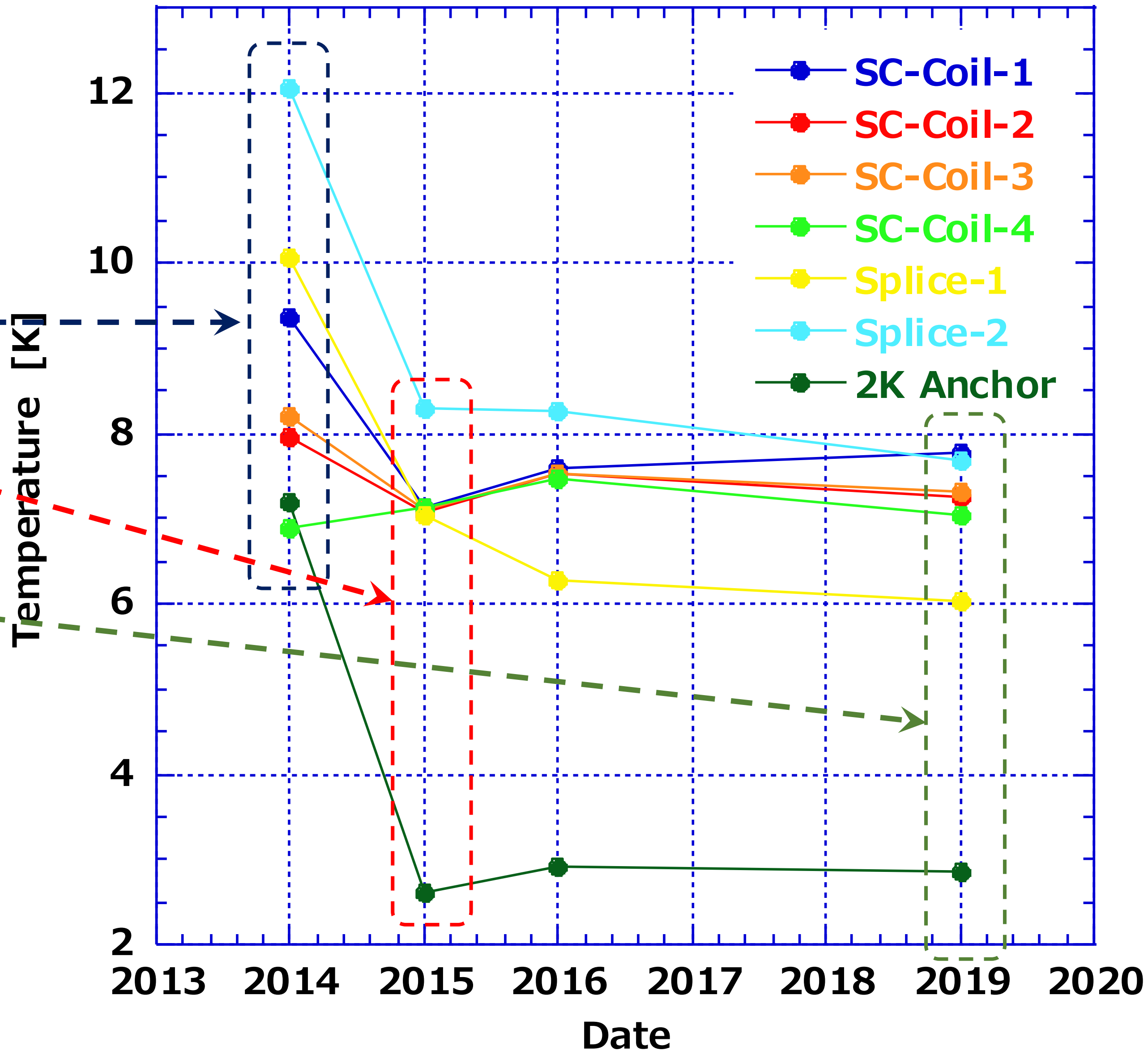
Table 3: STF SC Magnet R&D History

Date	Activity
2013/3/1	Fabrication started at FNAL
2013/9/20	Shipped to KEK
2013/11/12	Installation into STF CM1
2014/11/14	1st Excitation (quenched at 9.8 A)
2015/5～	HTC Current Lead Introduced
2015/11/1	2nd Ecitation (quenched at 25.6 A)
2016/11/14	Dipole Excitation (50 A)
2017～2019	All Current Lead Removed



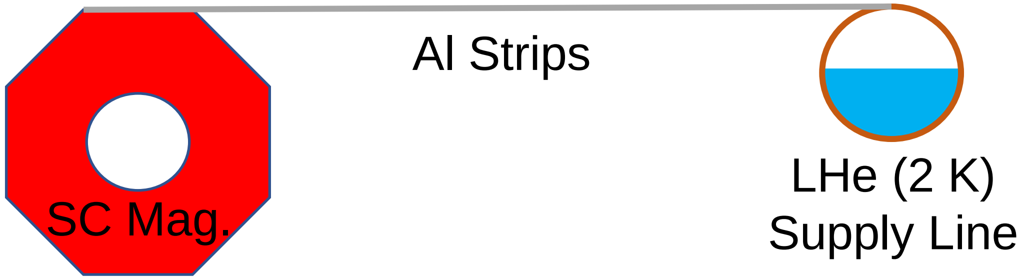
Conduction Cooling scheme of SCQ in STF CM-1

Temperature of SCQ in STF CM-1

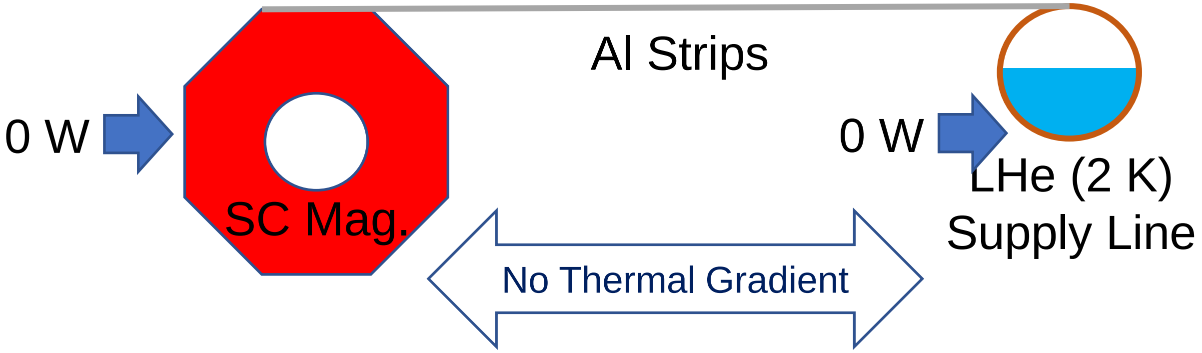


○ Model Magnet R&D in KEK Superconducting Test Facility

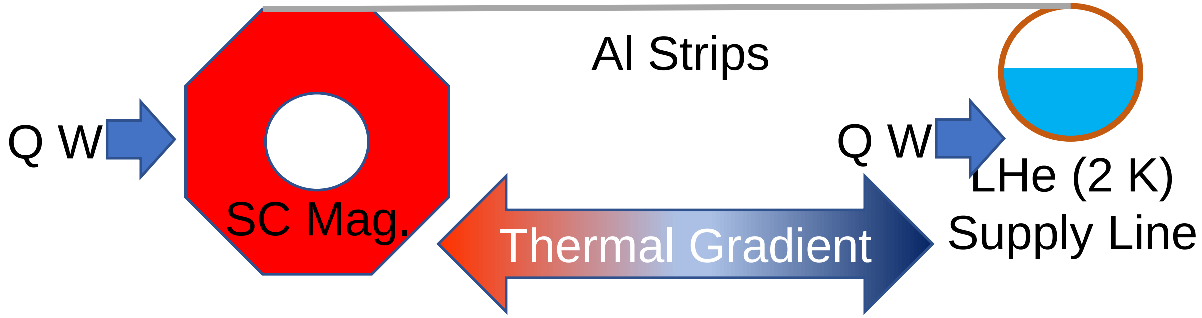
⓪ Magnet System in STF CM-1

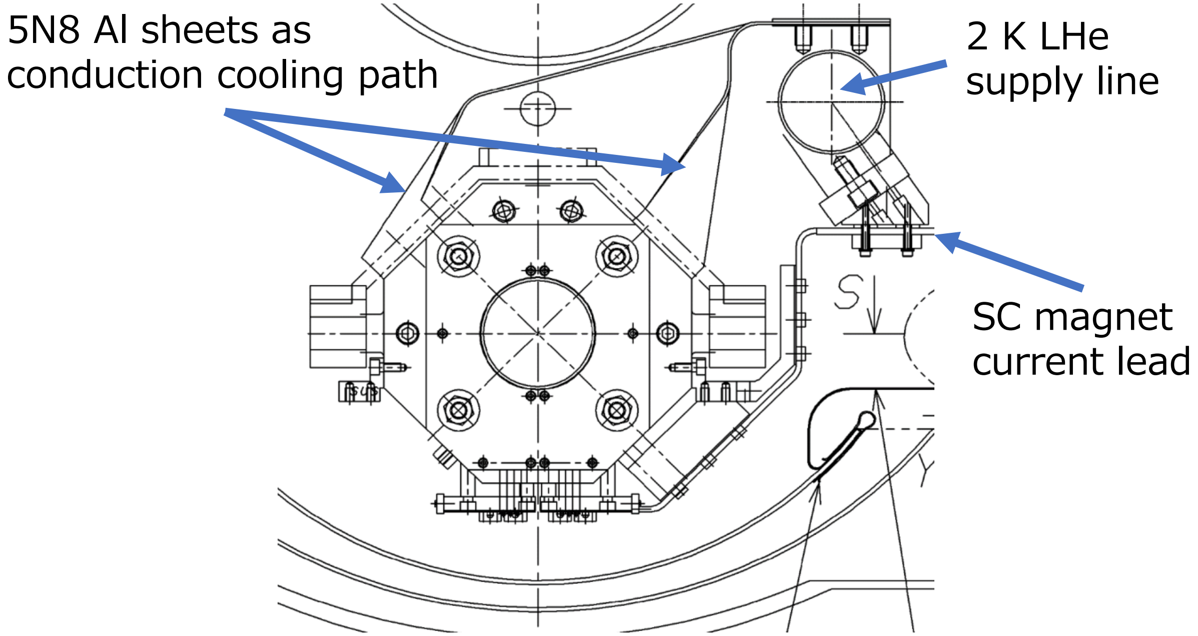


① No Heat Load from Outside (Ideal Case)



② With Some Heat Load (Actual Case)



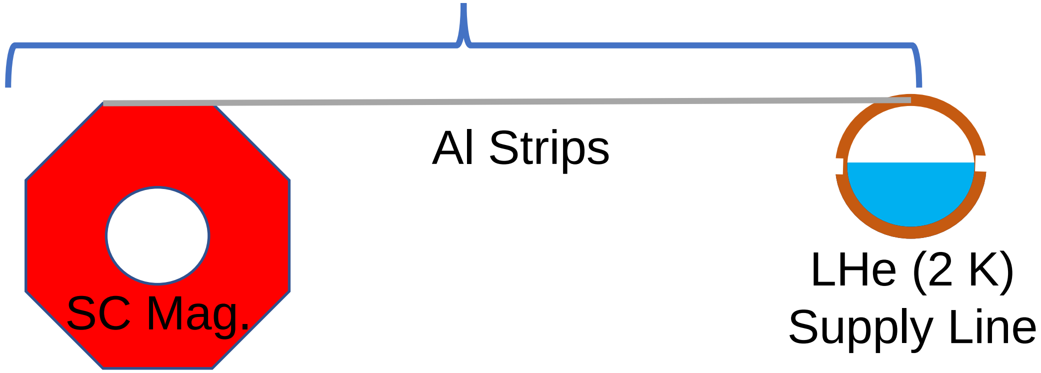


Conduction Cooling Scheme of SCQ in STF CM-1

- We have seen clear thermal gradient even after 3-month cooling operation between magnet (yoke and coils) and 2 K supply line.
- Using measured temperature information to evaluate the extraneous heat load, it seems about 1 W.
- Using FEM analysis, we have confirmed that about 1 W heat load reproduce the measured thermal gradient.

○ Model Magnet R&D in KEK Superconducting Test Facility

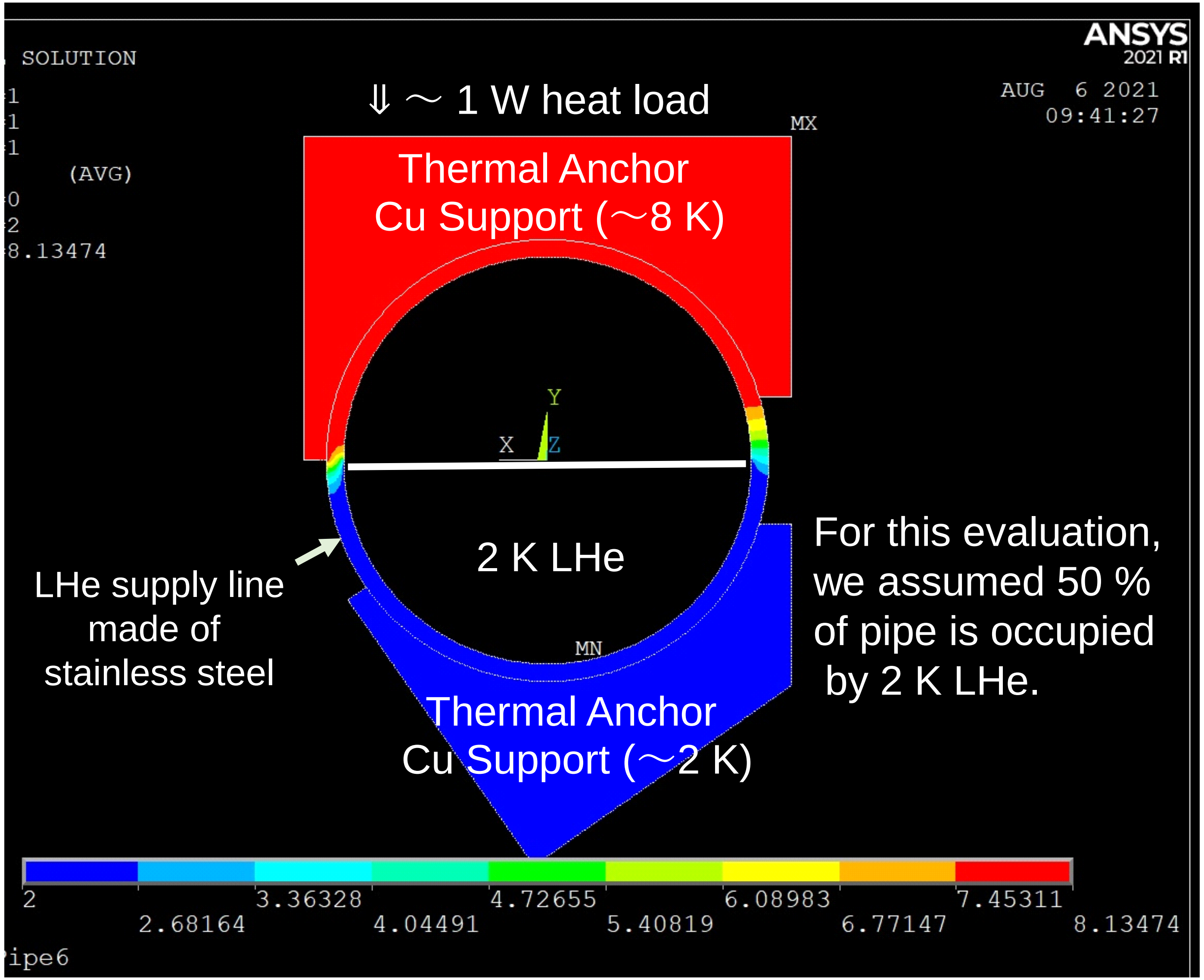
− Magnet(all coils and yoke) and thermal anchor Cu support show almost same temperature.



$$Q = \lambda \times \frac{\Delta T}{L} \times S$$: Fourier's law

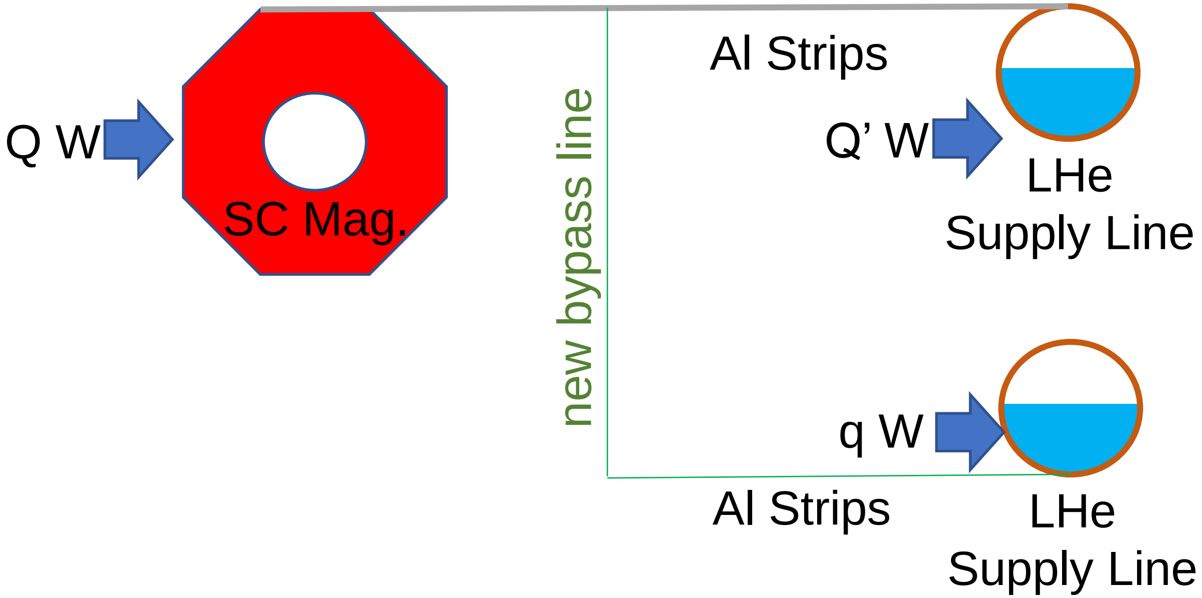
− Using measured temperature distribution and dimensions of configurations, carrying heat is estimated about 1 W.

− To confirm above evaluation, we used FEM to reproduce the measured temperature distribution. As a result, stainless steel pipe wall of the 2 K LHe supply line shows a large thermal gradient.



○ Model Magnet R&D in KEK Superconducting Test Facility

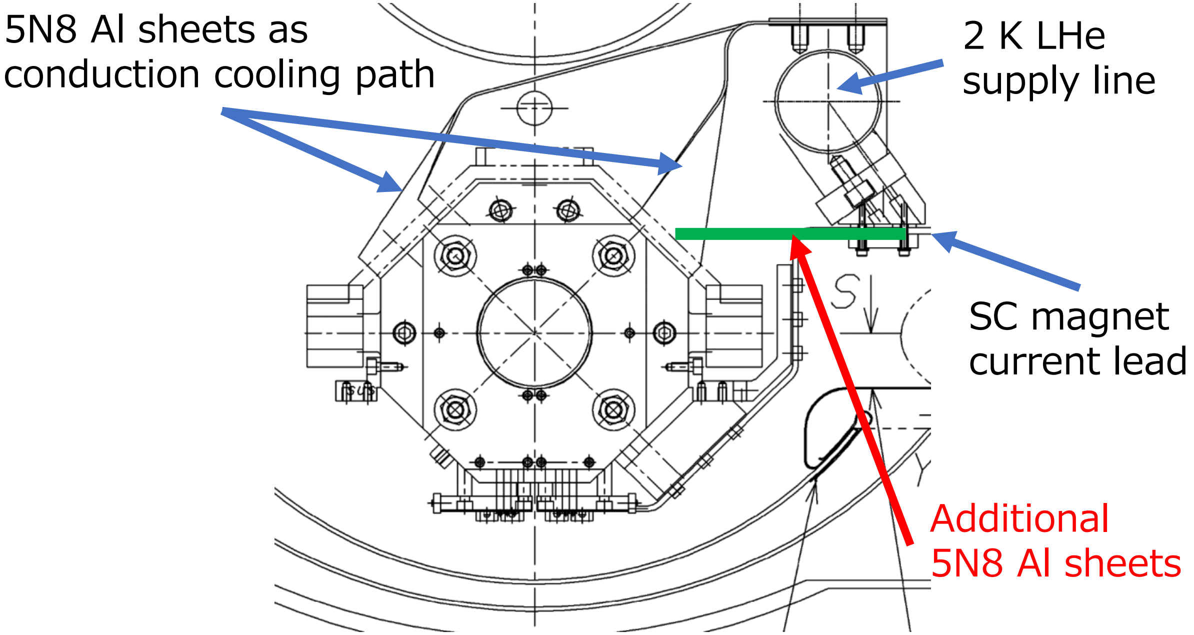
③ A Reinforce of the Thermal Anchoring



: Any magnets installed cryomodule are quite difficult to pull out for repair. So, we decide to add a new bypass line which directly connects the SCQ and bottom part of the 2 K LHe supply line.

$Q = Q' + q \ \ (= \sim 1W)$

no heat load reduction for Q.(still 1 W)

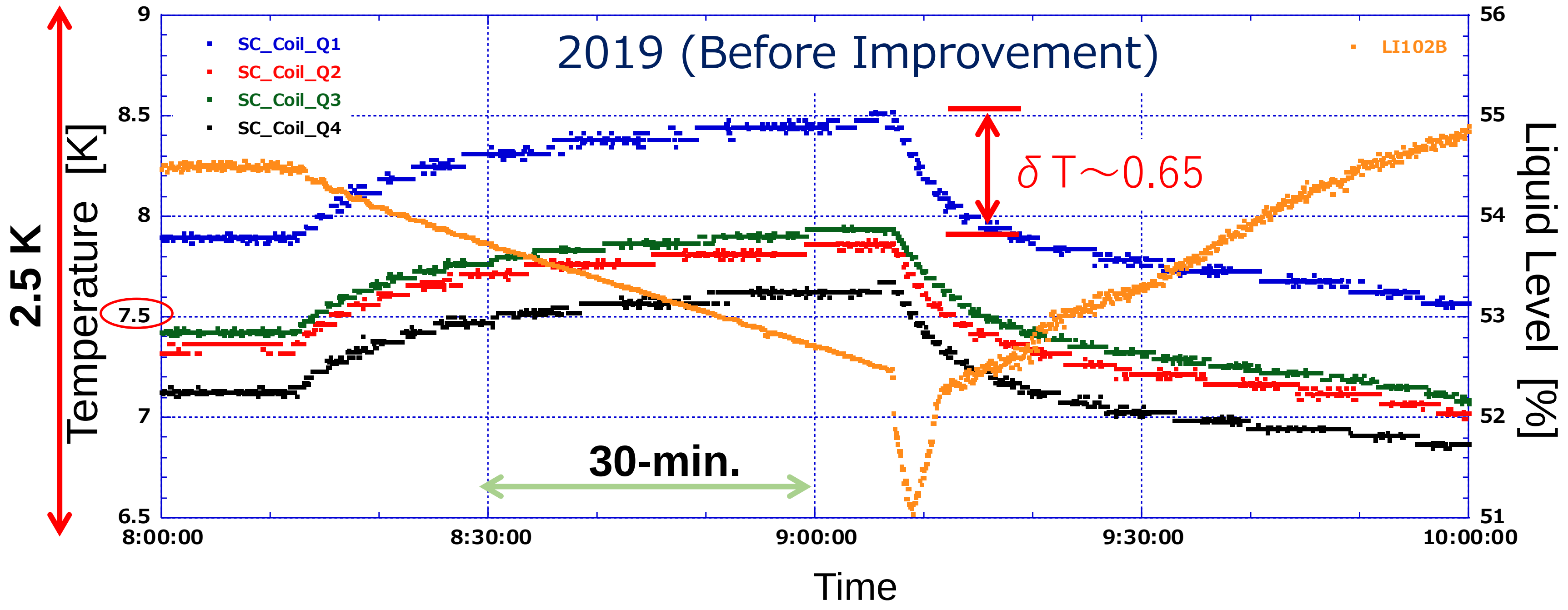


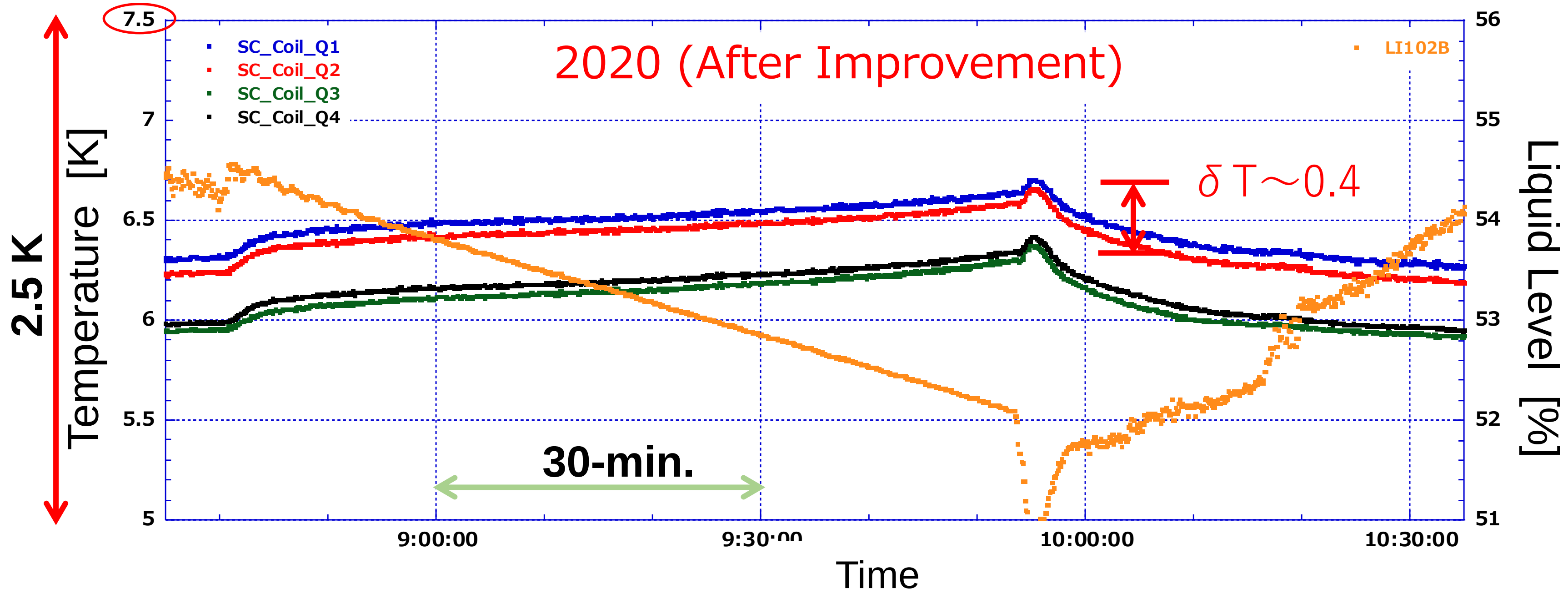
※ We have confirmed that HTS protects the heat load from room temperature well.

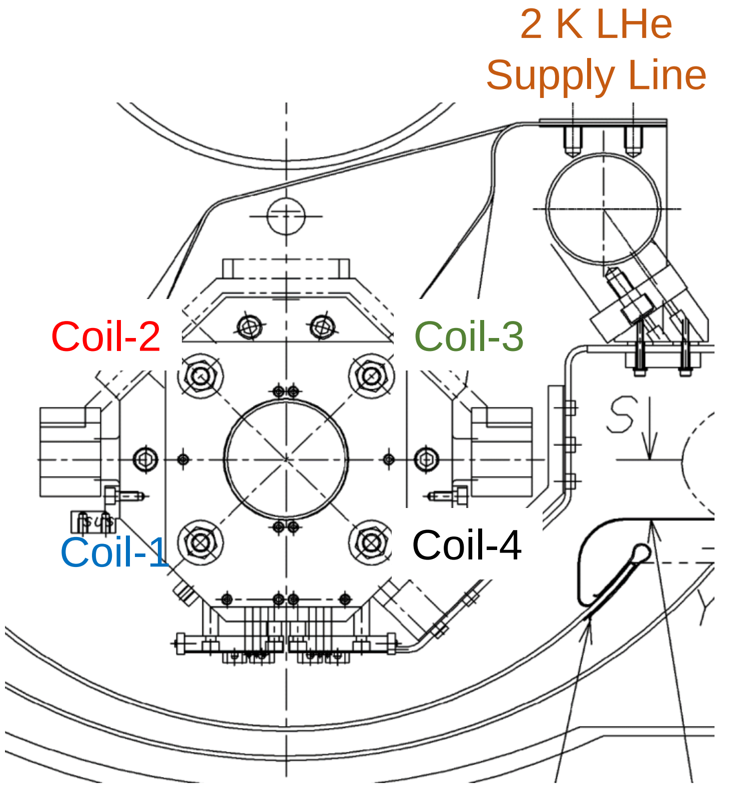
※ 2 K anchor point (bottom part of the 2 K supply) temperature shows almost 2 K correctly.

※ We have attached a new bypass line which connects the SCQ and the 2 K anchor point.

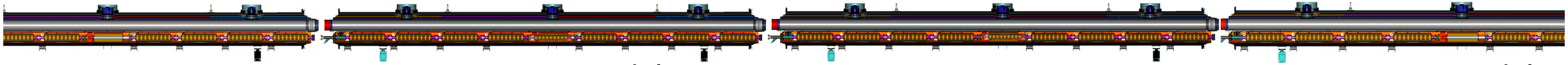
○ Model Magnet R&D in KEK Superconducting Test Facility



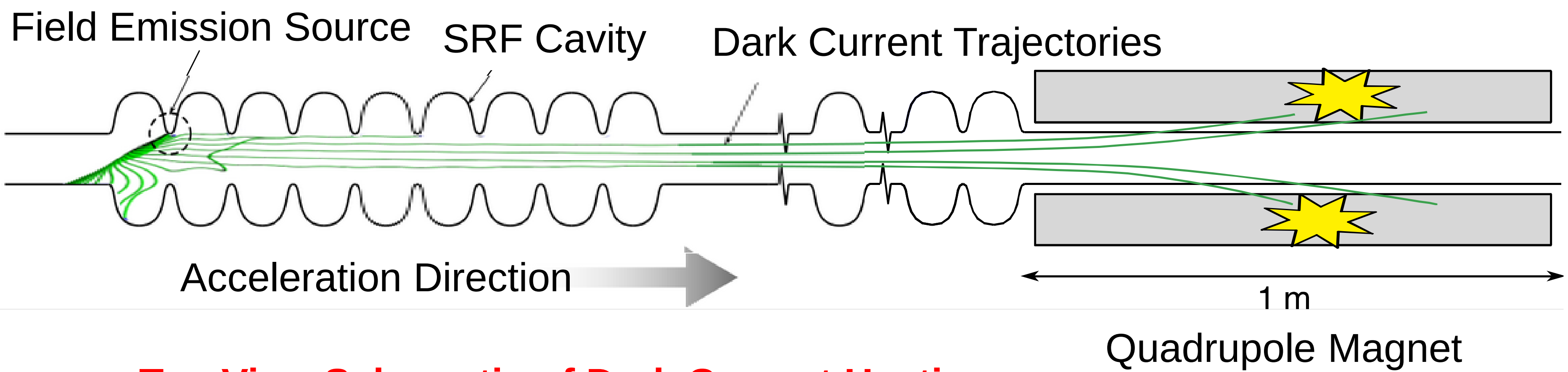


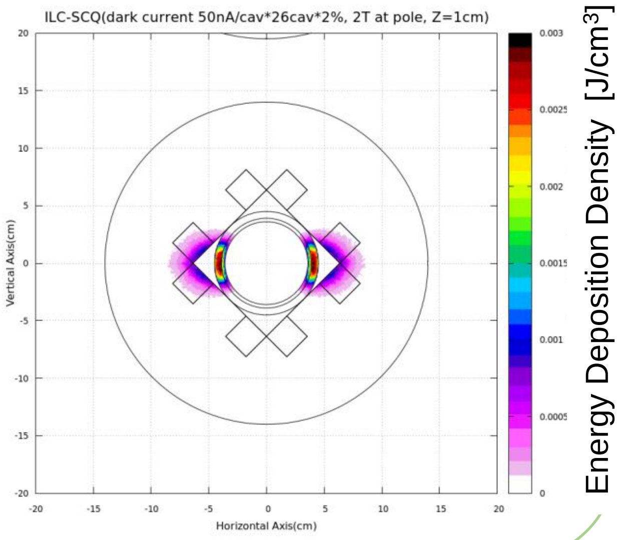


○ A New Issue for Quadrupoles of the Main Linac



Module Alignment for ILC Main Linac



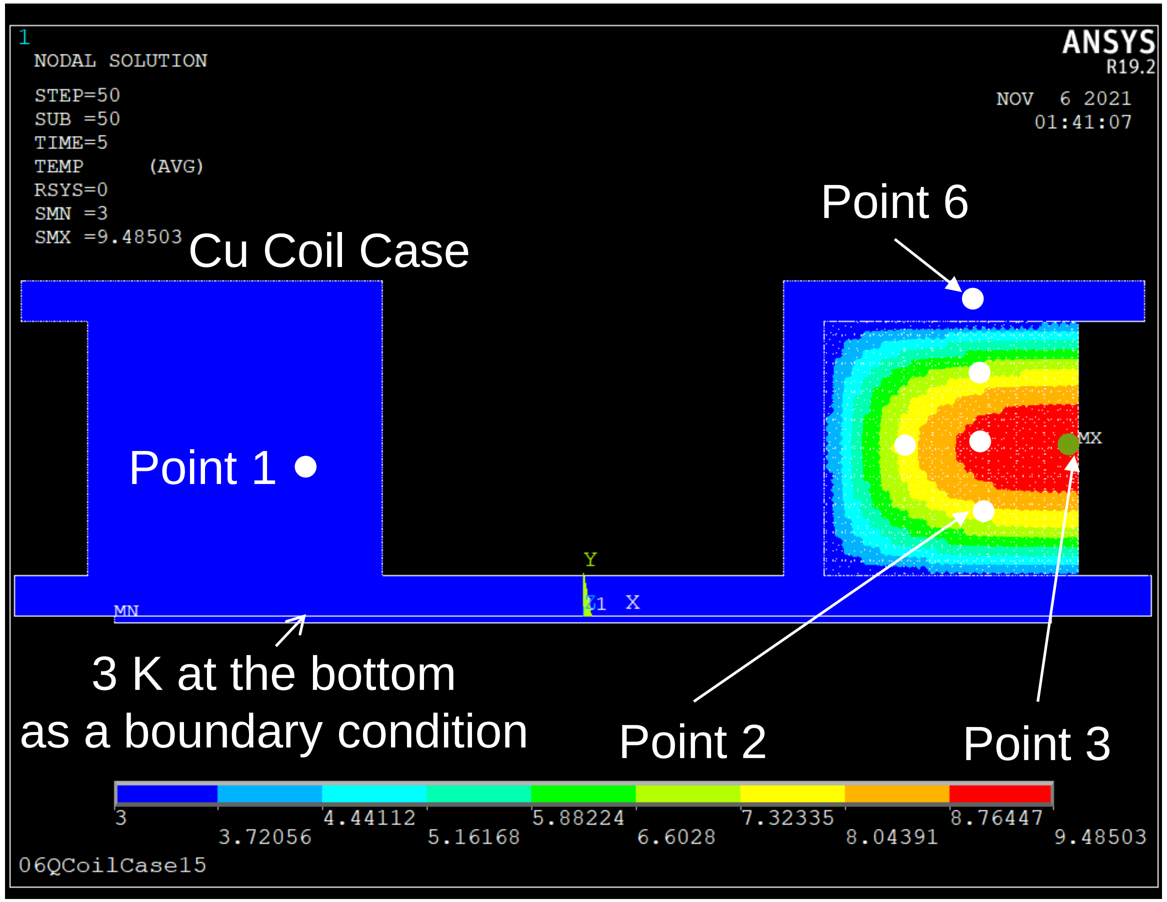


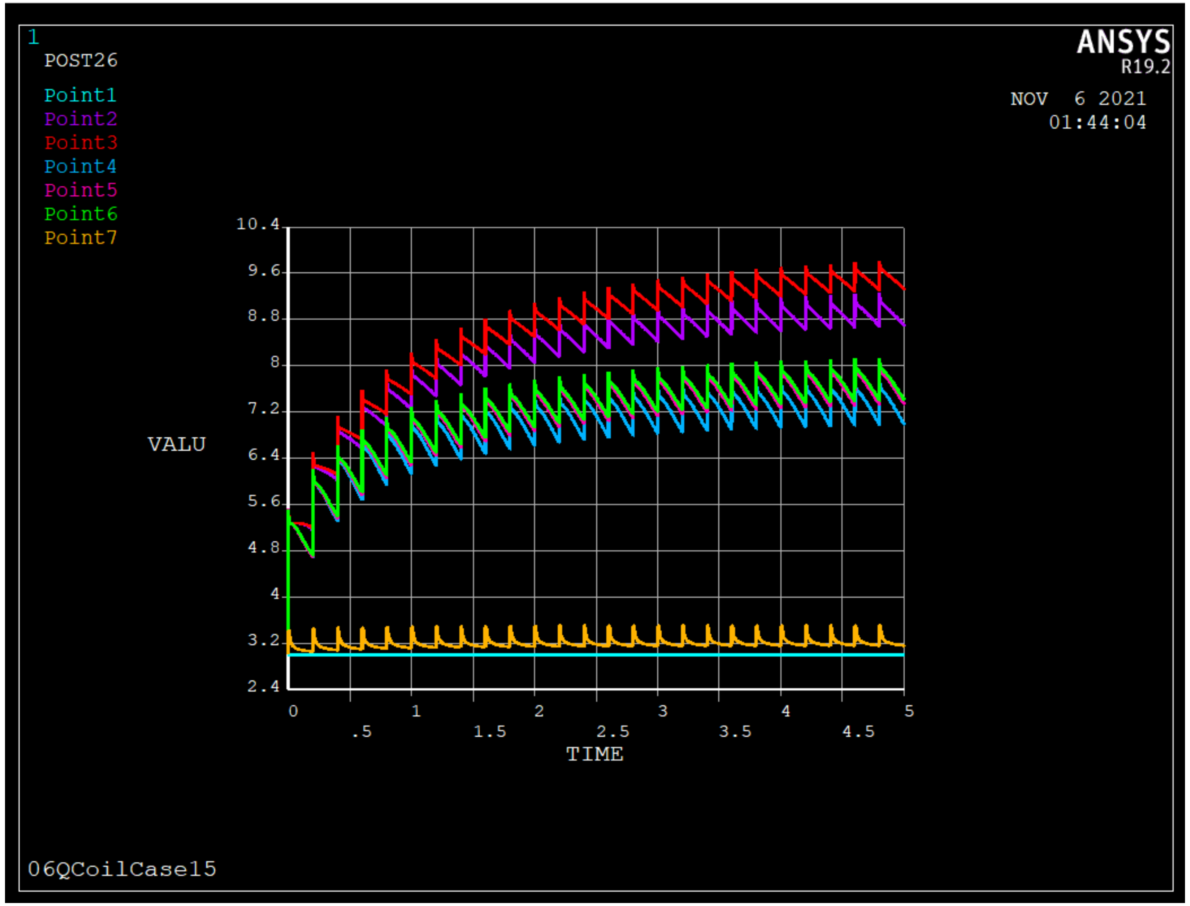
Top View Schematic of Dark Current Heating

- ○ Sources of Dark current (emitters) are randomly scattered inside of cavities.
- ○ All emitted dark currents are accumulated in between an interval of SC magnet packages (～ 38 m).
- ○ Each charged particles has almost speed of light, however, energy of them are not uniform.
- ○ Energy matching with appropriately aligned SC magnet package would not be achieved, and focus or defocus magnetic forces would bend the injected dark current and absorbed them by own coil and iron yoke.
- ○ As results of recent simulations, evaluated dark current amount is about 50 nA from one 1.3 GHz cavity, and energy deposition to the SCQ could reach about 5 W in 500 GeV ILC case.

○ A New Issue for Quadrupoles of the Main Linac

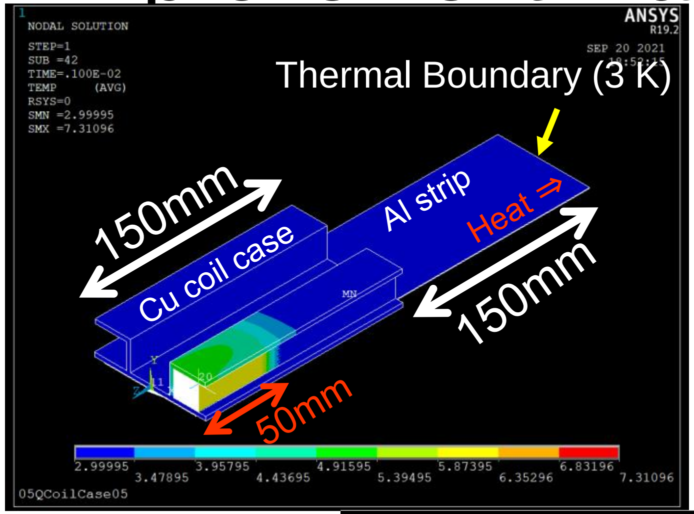
− FEM evaluation of Time-Dependent Temperature Evolution in a Coil Case was performed.



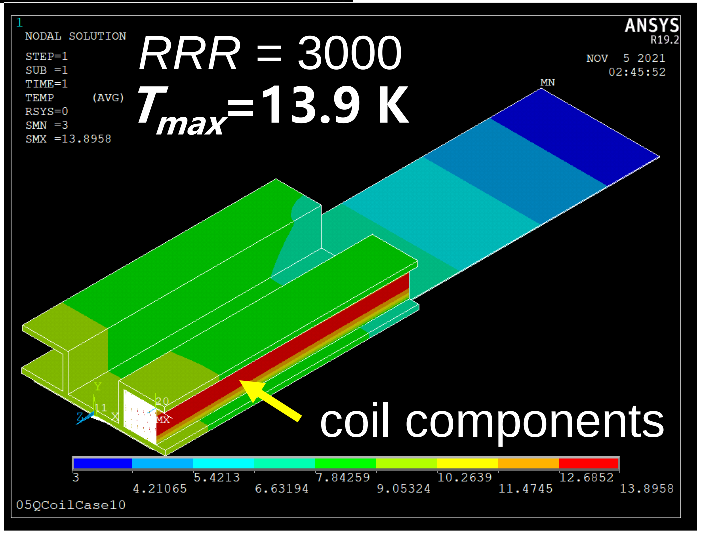


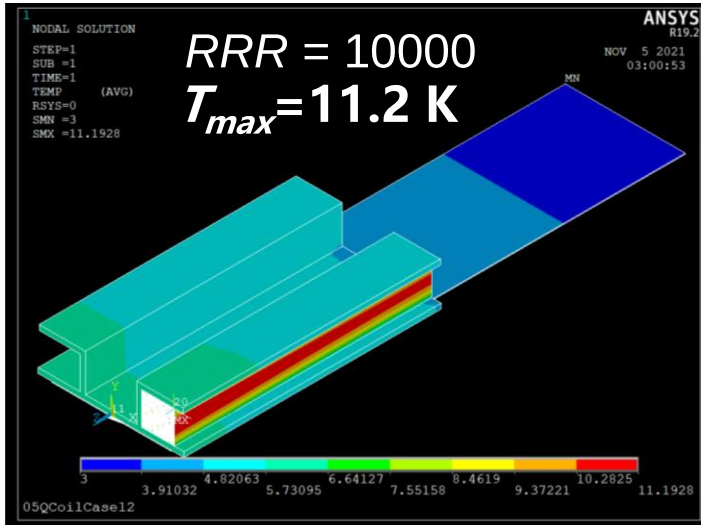
- ○ ILC adopts 1-ms beam with a 5-Hz repetition rate. This means the dark current would be also accelerated during 1-ms RF pulse.
- ○ In the above simulations, the coil is heated up for 1-ms with 1J and turned off in following 200-ms to demonstrate an actual ILC condition. ⇒ assumed energy deposition to one coil is 1.25 W.
- ○ The hottest coil region exceeds NbTi critical temperature within several seconds.

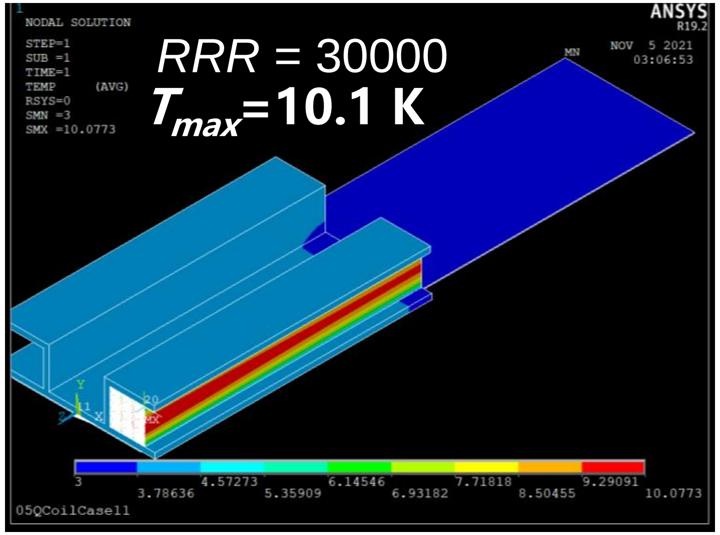
○ Improvement Plan of Dark Current Heating



- Heating effect of the dark current is evaluated with a model depicted left side.
- Components of the model consists of coil material (G10 and Cu), Cu coil case, and Al strip of 0.5 mm thickness.
- Assuming a 300mm coil (short model), and evaluate just a half section.
- The dark current heating effect is taken into account that only central volume of 50 mm length is heated with 1.25 W. (5 W shared by 4 coils.)
- A thermal boundary condition is fixed as 150 mm apart edge of Al strip is 3 K.



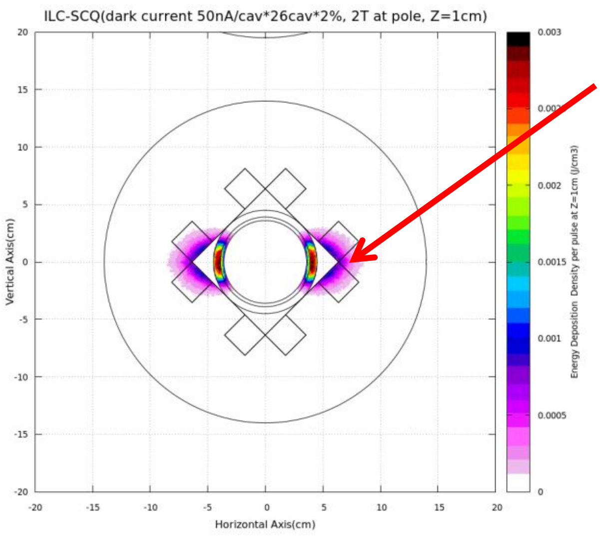




RRR of Al Strip	3000	10000	30000
Hottest Temperature of coil	13.9 K	11.2 K	10.1 K

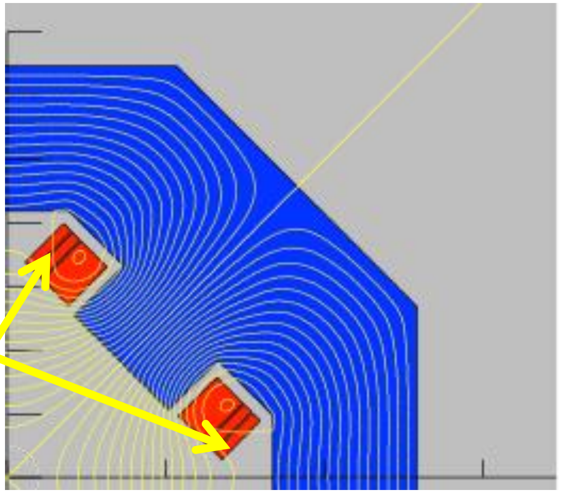
⇒ Even using extremely higher RRR Al strip, the coil center still remains hotter.

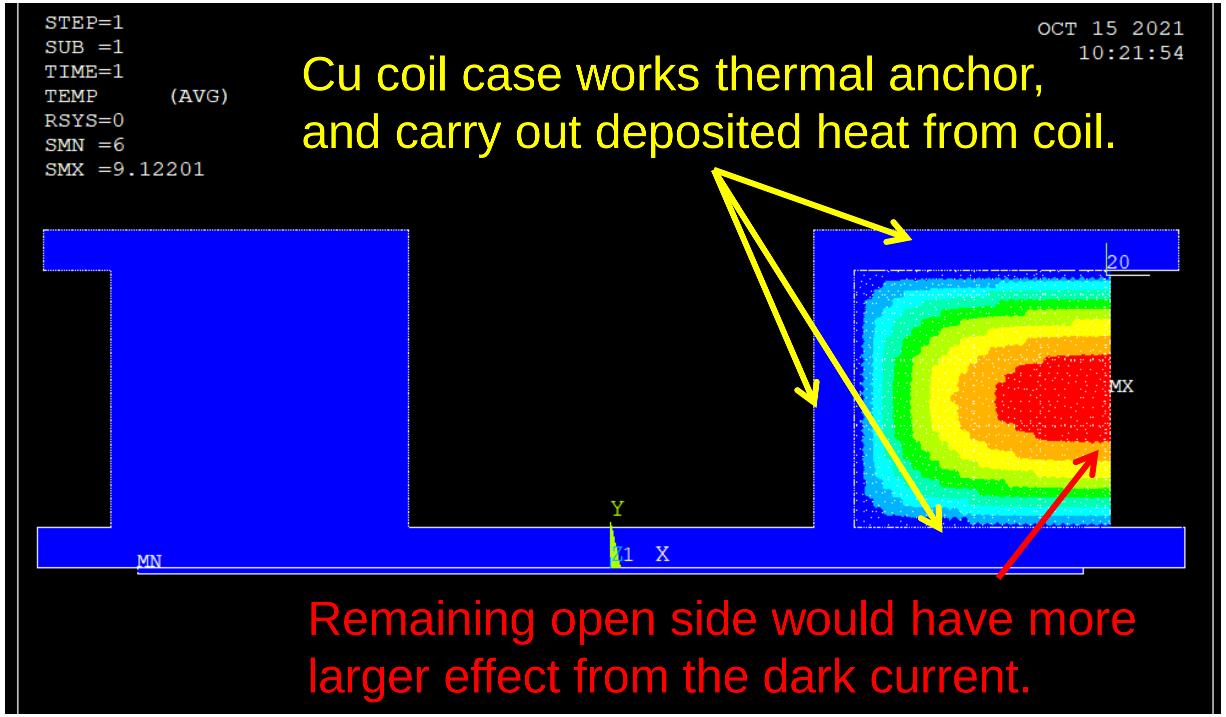
○ Improvement Plan of Dark Current Heating

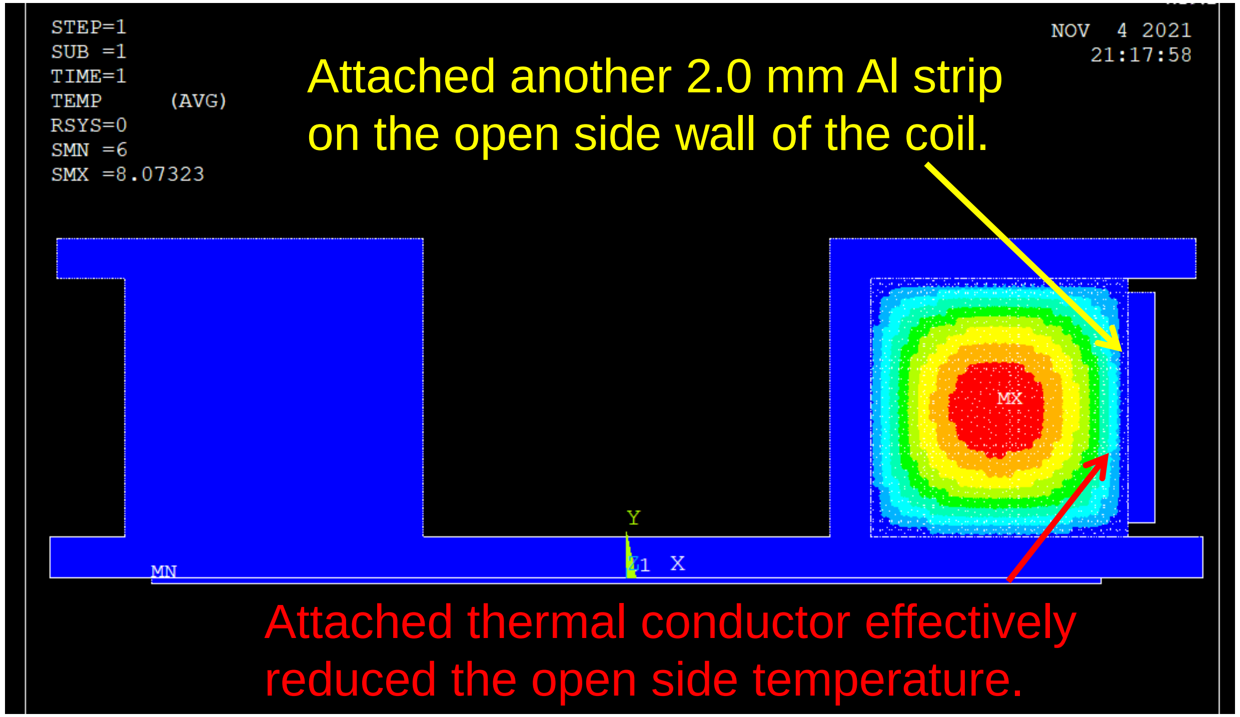


- The dark current heating has a characteristic temperature profile on the coil.
- When the dark current hits on the coil, open side of the coil region has larger energy deposition from the current.

- Right hand side picture shows a part of design flux line profile at *I* = 82 A.
- The coil open side shows rare flux lines, and this is helpful to avoid an increasing magnetoresistance of attached metal.

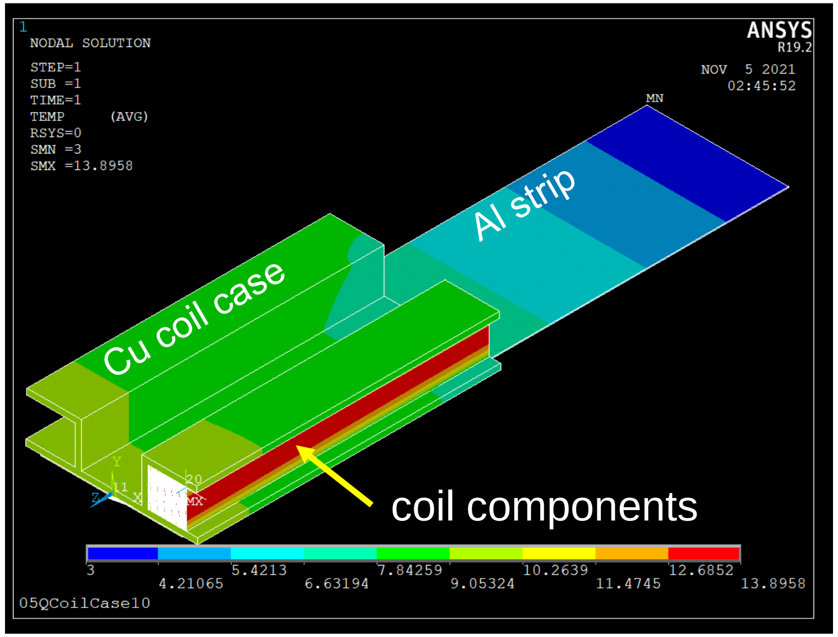


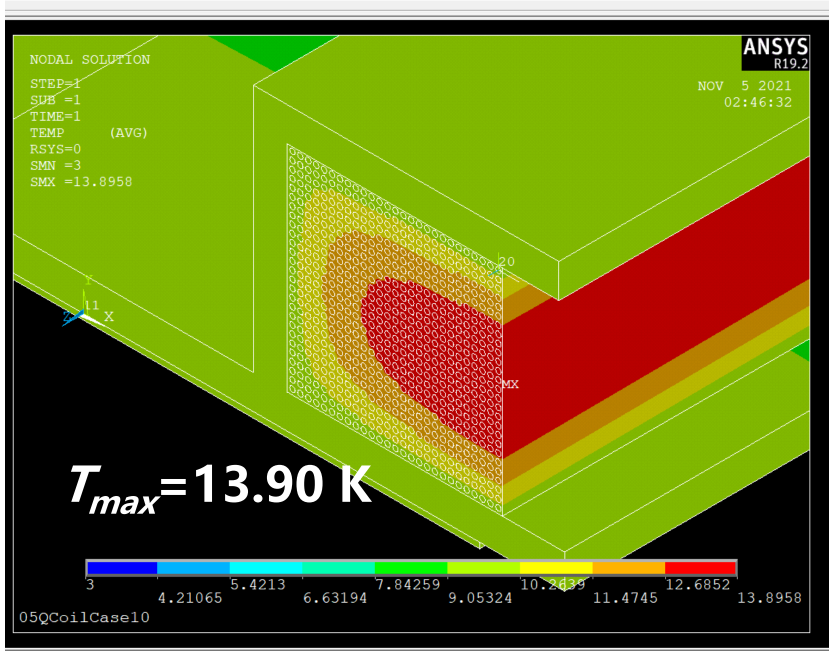




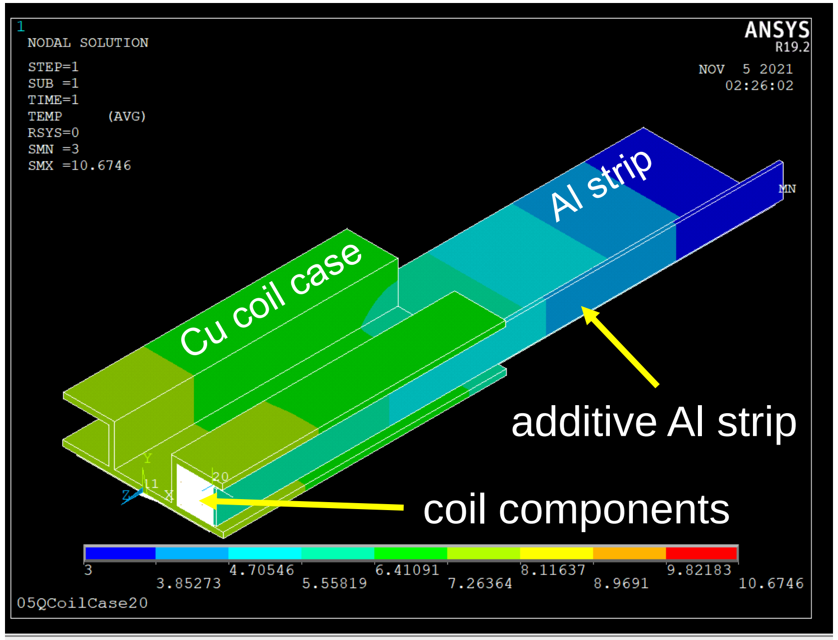
○ Improvement Plan of Dark Current Heating

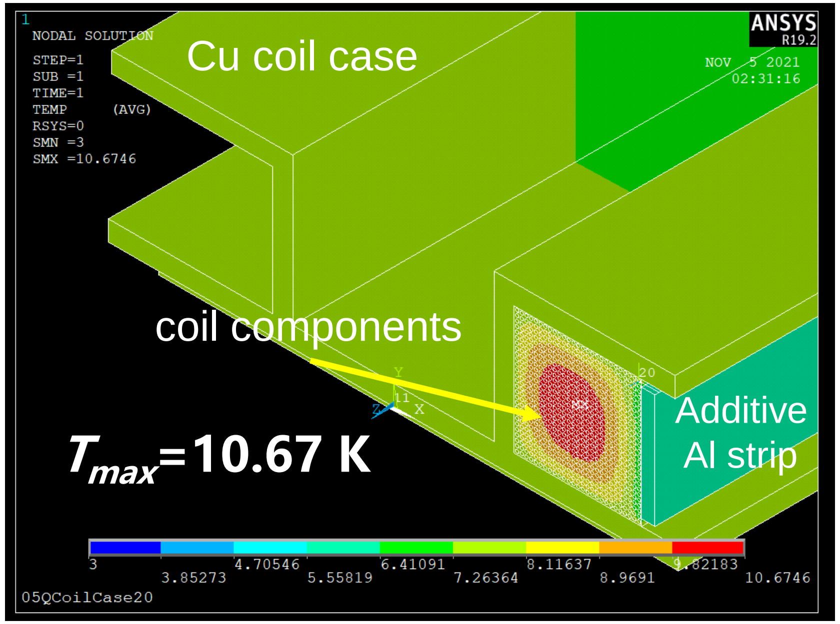
Conventional Heat Extraction Scheme





Additive Al Strip Attached on the Open Side Wall (*RRR* = 3000)





○ Summary

− As a demonstration conduction cooling R&D, we have developed a short model superconducting magnet and installed it into KEK STF.

− After some improvements, we have successfully operated the SCQ in CM1 cryomodule during STF machine operation periods.

− Making use of lessons learned in STF and also SuperKEKB activities, we have started a new R&D program with a new model magnet to be sustainable against the dark current heating which recently recognized to be a major issue for the high gradient linac machine such as ILC.

− To avoid unexpected quench risks, we evaluate heat profile evolutions in the SCQ using FEM, and propose a new conduction cooling scheme for thermal link from the magnet coil and 2 K supply line.

− To apply our improved anchoring scheme, the model coil and magnet will be tested with similar heat load to the dark current in near future.

A part of this work was supported by JSPS KAKENHI Grant Numbers JP18K04951.

Back Up Picture

Model (Coil+ Case + Al foil + Copper + SUSpipe)